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The Influence of Human Factors on Operational Efficiency

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ABSTRACT

This paper adopts a socio-technical systems approach is taken to examine how airline operational efficiency can be enhanced from a human factors perspective. Four case studies are examined from this viewpoint: increasing operating efficiency on the airport ramp; increasing efficiency through flight crew rostering; increasing efficiency by promoting direct routing; and increasing efficiency through greater flight deck automation. It is argued that the increases in operational efficiency (which is taken to be almost synonymous with cost) taking solely a human factors perspective will be minimal. To truly enhance operating efficiency the human component in any system cannot be examined in isolation from all other components.

Keywords: Socio-technical Systems; Human Factors; Automation; Ground Handling; Flight Time Limitations; Free Flight

INTRODUCTION

The term 'efficiency' in this context is somewhat difficult to define. Traditionally, a treatise of this type should start with a dictionary definition, for example:

'**Efficiency** *n.* The quality or degree of being efficient'

'**Efficient** *a.* …productive of desired effects; especially: productive without waste.' (Webster's Third New International Dictionary).

In the context of civil aviation 'efficiency' is most often, either directly or indirectly, related to cost; 'waste' refers to a waste of time or money. However, for the sake of 'efficiency' the conclusions to this treatise can be stated up front. Good Human Factors *will not* significantly increase efficiency by itself. On its own, only small incremental gains may be made. A wider, sociotechnical perspective needs to be adopted before any true efficiency gains incorporating good Human Factors can be realised.

In the aerospace industry 'Human Factors' has become synonymous with Crew Resource Management and ergonomics. However, there is much more to the discipline than this. All boundaries and divisions created by man are artificial, and subject matter boundaries in the complex world of aviation operations are both artificial and arbitrary. However, when addressing a topic such as the role of Human Factors in operational efficiency some structure is essential. As a result this discourse is organised around a sociotechnical systems framework to impose some structure on the chaos. This structure also reflects the organisation and operation of an airline and clarifies the influences that effect the manner in which it operates. The framework used is the five ‘M’s model (Harris & Smith, 1997; Harris & Harris, 2004; Harris & Thomas, 2005).

THE FIVE ‘M’S MODEL OF SOCIOTECHNICAL SYSTEMS

The operation of an airliner is not just about the integration of pilot (hu*Man*) and aircraft (*Machine*) to perform a flight (or *Mission*) within the constraints imposed by the physical environment (*Medium*). This approach needs extending to encompass the societal environment, an additional aspect of the *Medium*. The role of *Management* is also central to safety and efficiency.

The (hu)*man* aspect of the five ‘M’s model encompasses issues such as the capabilities of the end user, their size and fuel requirements (elements falling within the ‘traditional’ realms of psychology and ergonomics). From a user-centred design perspective, the (hu)*man* is the ultimate design forcing function. It cannot be changed. When (hu)*man* and *machine* elements come together they perform a *mission*. It is usually the *machine* and *mission* components on which developers and designers fixate. Note that when discussing ‘efficiency’, it is the efficiency of performing the *mission* which is being referred to.

However, designers and engineers must not only work within the bounds of the technology, the capabilities of the end-users and the physical aspects of the *Medium*, they must also abide by the rules and norms of society (the societal *Medium*). The performance standards for human-machine systems are primarily determined by societal norms (regulations) *e.g.* the level of redundancy required (aircraft certification) or minimum standards of user competence (flight crew licensing). *Management* must work within these rules. The airline *Management* is the link between the (hu)*Man*, *Machine*, *Mission* and *Medium*. It performs the integrating role to ensure compliance with operating, licensing and certification requirements, and it promotes safe and efficient operations.

The inter-relationships between the five 'M's are described in Figure 1. In the case of an airliner, the pilots fly the aircraft to achieve a well-defined goal (the union of (hu)*Man* and *Machine* to perform a *Mission).* The *Management* tasks this *Mission* and ensures the crew and aircraft conform to the regulatory requirements (societal *Medium)* and are fit to endure the demands placed upon it by the physical *Medium*.

INSERT FIGURE 1 ABOUT HERE

The *Mission* of a commercial aircraft is a simple one: to deliver passengers at the greatest possible speed and comfort while maintaining the highest possible standards of safety and economy. These contradictory requirement define what is characterised as 'efficiency, but therein lies the catch. Regulatory objectives are specifically aimed at enhancing safety. Organisational aims, however, need to balance safety against performance, comfort and economy.

To illustrate how efficiency gains may not be realised through the modification of just one part of the system, four case studies are examined in what follows: The human dimension to increasing operating efficiency on the airport ramp; increasing efficiency by flight crew rostering; increasing efficiency through direct routing; and increasing efficiency through increased flight deck automation.

INCREASING EFFICIENCY ON THE AIRPORT RAMP

The prime drivers to enhancing operational efficiency in the last decade have been the low-cost carriers. These operators now command a significant proportion of the market and have been responsible for the larger airlines having to achieve increases in efficiency to remain competitive. As margins are low on each seat sold, load factors need to be high and turnarounds need to be swift. However, some attempts to decrease operating costs may have a 'hidden' price. This is evident when decreasing the aircraft's time on the ramp is examined.

An aircraft on the ground is both failing to generate revenue and is also costing the airline money as airport gates are charged by the minute. In terms of *Mission* efficiency, it is beneficial to minimise this time, something the low cost operators have been successful in achieving. However, a broader perspective needs to be taken, but before going further it needs emphasising that *all* aspects of *Management*, directly or indirectly, involve people. What appear to be simple contractual or accounting decisions taken in an office have a human element associated with them which influences both airline safety and efficiency.

In 1997 the cost of accidents and incidents on the airport ramp was estimated to be $2 billion, much of which was uninsured losses. However, these direct costs represent only a small proportion of the overall cost, *e.g.* damage to aircraft; repair and replacement of damaged parts. Indirect costs are far more substantial, *e.g.* compensation; re-scheduling of services; service fees; replacement aircraft; loss of perishable cargo, *etc*. Airports Council International (1996) reported that 84% of ramp accidents occurred when ground equipment struck an aircraft (known as 'ramp rash'). The following are typical:

> *'Refuelling vehicle reversed into a/c engine, causing damage to the engine fan cowling. No external visual assistance available to driver of vehicle.'* (Accident to Boeing 737-200, Manchester, February 1994: UK CAA database).

> *'RH wing tip hit by lorry. Driver allegedly had no "banksman" to marshal the reversing lorry onto the aft cargo door.'* (Accident to Boeing 737-300, Edinburgh, November 1996: UK CAA database).

> *'[Company name] catering truck backed into LH aileron causing damage to the LH aileron and wing structure, after servicing another airplane. Driver of truck failed to follow [company name] procedures outlined in company station operations manual (SOM), by not utilizing a guide.'* (Accident to Avro 146 RJ85A, Minneapolis, October 2000: FAA Incident report 2000102902463 C).

The conduct of personnel and vehicles on the airport ramp is prescribed in company procedures, regulations and advisory material *e.g.* CAP 642 (CAA, 1995); IATA Airport Handling Manual (IATA, 1998). In the accidents described, if requirements had been followed it is unlikely that these incidents would have occurred.

An observational study at a major UK airport (Thomas, 1998; Harris & Thomas, 2001) showed that deviations from recommended procedures when servicing aircraft were commonplace. For example:

- In 68% of all turnarounds, ground equipment was positioned around the aircraft without the help of a guidesman.
- During 5% of turnarounds, vehicles were driven under the wings of aircraft without exterior guidance.
- In 19% of turnarounds at least one vehicle was reversed up to the side of the aircraft without the external guidance.

However, these observations merely describe *what* happened, not *why*. When the reasons underlying such behaviours are proffered a more complex picture emerges. The most common explanation for such deviations in procedures (what Reason, 1990 terms 'violations') was one of time and money. Aircraft servicing is usually provided by a sub-contractor. To keep prices down and margins high, sub-contractors are under considerable time (hence financial) pressures. Competition is encouraged to suppress prices. To remain competitive, sub-contractors operate with the minimum number of personnel. As a result, a common explanation for procedural violations was that 'no one was available to see me back' or 'there was no time to get someone to help me reverse'. Reason (1997) suggested that such violations are quietly overlooked by management (until something goes wrong). These suggestions were given strong support by Bennett & Shaw (2003) in an ethnographic study of ramp workers. Deviations in safe operating procedures were frequently condoned (in fact they were tacitly encouraged) to ensure on-time departures and maintain the profitability of the ground servicing supplier and the airline.

The root cause for such behaviours, though, resides within the contracts branches of the airlines. Competition between suppliers keeps prices low and punitive clauses are written into contracts to punish late or non-delivery. There is an argument to be made that if margins were not eroded to the bare minimum, then incidences of ramp rash would begin to decrease. There *would* be someone available to guide the driver of a reversing truck. The provision of supplies may cost slightly more but the airline may save large amounts from the reduced requirement for aircraft repair, delays, insurance premiums, *etc*. Arguing that a sub-contractor is responsible for these aspects of ramp safety is only a partial solution and does not address the root cause of the problem. Taking a wider view of financial management which encompasses direct and indirect effects on worker behaviour may be beneficial in terms of efficiency and safety. The action of people writing and negotiating contracts does influence human behaviour. Paying more may ultimately promote efficiency *and* cost less.

INCREASING EFFICIENCY THROUGH FLIGHT CREW ROSTERING

High levels of efficiency in low-cost airlines require that crews are utilised to the maximum but without resulting in stress and fatigue. This has not always been the case (Bennett, 2003). These pilots may fly up to eight sectors in a working day. Little time will be spent in the cruise. Most time will be devoted to the high workload phases of departure, approach and landing, and turnaround on the gate. Gander et al.

(1988) suggested the problems associated with these operations were twofold: irregular hours of work and high workload from the number of sectors.

Airworthiness authorities have strict duty time limitations. A survey of these by Cabon *et al.* (2002) showed 13 criteria used in determining rest periods between flights (*e.g.* number of legs flown; reporting time; duration of legs). No country, however, used more than 11 factors, and some used only two or three. These duty time regulations highlight the conflicting requirements of safety and efficiency. Safety would be enhanced with more rest between flights but this is economically inefficient. More rest periods requires more crew and higher away from home accommodation costs.

In recent years, incidences of stress and depression have began to increase as a result of factors such as worries about company stability and large numbers of last minute flying schedule changes, which are common as a result of crew being used more 'efficiently' (Little *et al.*, 1990). These factors are also associated with drinking and flying behaviour (Maxwell & Harris, 1999). UK Health and Safety executive estimates that work-related stress, depression or anxiety account for thirteen million lost working days every year in Britain (HSE, 2005).

In a trial of a new flight rostering system (Stewart, 2005) it was found that changes could bring about both safety *and* efficiency gains. However, as a result of the regulatory *Medium* these benefits were not easy to achieve. Stewart noted that prior to the trial rostering practices were compliant with CAP 371 flight time limitations guidelines (CAA, 2004) but that these were written four decades ago. In the normal flight roster crews would work six days 'on' and three days 'off':

- Day 1: backward diurnal phase shift - starting 05:00
- Day 4: forward diurnal phase shift - starting 13:00
- Day 6: end work at 23:00-24:00 with an option to extend duty to 03:00.

This roster resulted in decrements in performance as the six days 'on' progressed. In the trial the company was granted a temporary waiver from current flight time legislation to evaluate a slow wave shift pattern (five 'earlies'; two days off; five 'lates'; four days off). The revised shift pattern was found to:

- Reduce operational risk.
- Produce less fatiguing work patterns and reduce crew duty hours.
- Produce a reduction in insurance liability of the order of £4 million.
- Improve crew productivity by 7%.
- Increase roster stability.
- Improve crew lifestyle and reduce sickness.
- Improve pilot retention and reduce training liability.

All of these factors represent an increase in operational efficiency. It needs to be noted, though, that the company had to be granted a temporary waiver from UK flight time legislations. Potential gains in efficiency (and safety) from the (hu)*Man* component in the system are often bounded by regulatory structures which need to be changed before advances can be made.

The effects of the *Mission*, repetitive sectors, operating across time zones and working unsociable hours are only a few aspects impacting on the (hu)*Man* in the system. The recent economic *Medium* has made a significant transformation in the operation of airlines considerably influencing the utilisation of the human resources within them.

INCREASING OPERATING EFFICIENCY BY PROMOTING DIRECT ROUTING

Air Traffic Control oversees an aircraft on every step of its journey. Prior to takeoff, pilots inform ATC of their flight plan and are allocated a take-off slot, given weather information, and informed of restrictions concerning the areas over which they will fly. Once in the air they are passed from ATC at the airport to *en route* air traffic controllers. When being handed off from one sector to another pilots give a full status report to the new controller. This process is repeated until the aircraft is near its destination, where they are given a final altitude and position and are allocated a slot and runway for landing. This is an extremely inefficient way of flying from A to B. It is not the most direct route and it does not make best use of the *Medium*, *e.g.* prevailing winds and optimum altitudes for performance.

Future air traffic management (ATM) practices will require aircraft to navigate in a different manner. This concept, known as Direct Routing or ‘Free Flight’ will significantly affect the pilot’s role and responsibilities. In Free Flight, responsibility for ATM will be delegated to the flight deck (self-assured separation). Aircraft will fly direct routes and manoeuvre freely at their optimum speed and altitude, without consultation with ATC. IN this way, they will spend less time in the air and use less fuel, significantly increasing efficiency. The impetus to move to such a system is also driven by the fact that the current system is inefficient in its use of the airspace available and unless changes are made, it will be impossible to cope with the increasing growth in air traffic. For example, it is expected that air traffic in Europe will double by 2015 (Eurocontrol, 2002).

However, changes to the physical airspace demand wide-ranging changes throughout all other components of the system. To optimise efficiency gains as a result of changes in the *Mission* both ATC and aircraft need to be re-equipped with new navigation and surveillance equipment (*Machine*); crew need to be trained to use this equipment and associated new procedures (hu*Man*); company management is responsible for integrating these *mission*, *machine* and hu*man* aspects and international regulatory agreement is required for the approval of equipment and operation of Free Flight airspace.

Many human factors specialists a currently working in this area. Changes in the airspace to allow free flight cannot be fully exploited if aircraft are not equipped with suitable display technology to allow pilots to manoeuvre to maintain separation from other traffic, avoid weather and undertake other aspects of real-time flight planning. Much work is being embarked upon developing such Cockpit Display of Traffic Information systems. NASA Ames research centre has engaged in a great deal of effort developing such systems (see http://human-factors.arc.nasa.gov/ihh/cdti/cdti.html). Work has principally centred on the real-time representation of 4-dimensional traffic information to aid situation awareness and decision making (*e.g.* Johnson et al, 1997; Johnson et al; 1999) and the development of rules for resolving airborne conflicts (*e.g.* Johnson et al., 2005). However, without automated assistance pilots were found to be inefficient at resolving conflicts, (Johnson et al., 2003), clearly demonstrating that training is also required to complement display design to maximise efficiency

However, while resolving potential conflicts is a central part of the pilots' new tasks it is not the only one. For utilisation of Free Flight airspace considerable effort will need to be expended on training and educating pilots in all aspects of aircraft performance, *e.g.* the effects of altitude and temperature; wind; and conserving energy in both the climb and descent phases. Further increases in automation may help to some extent, however, simply continuing to increase the degree of automated assistance is not a universal panacea in increasing operating efficiency.

INCREASING EFFICIENCY THROUGH INCREASED FLIGHT DECK AUTOMATION

Weiner and Curry (1980) probably suggested that automation offers benefits in four basic areas: Safety; Reliability; Economy and Comfort. Ignoring the latter as it falls outwith the scope of this discourse, without a doubt, automated assistance has contributed significantly to safety, for example CAT III autoland capability. This has also had the simultaneous effects of increasing on-time arrivals and reducing the number of weather-related diversions, hence dramatically increasing operational efficiency. However the fallacious argument that safety can be improved by removing the operator from the system, thereby avoiding error, must be avoided. There are three problems with this approach. Firstly, automated devices are designed and built by human beings (just the nature of error changes). Secondly, such devices are not perfect and have the potential for generating errors. Thirdly, a highly trained individual who understands the automation is required to monitor and intervene when automation parameters are exceeded or an unexpected event in the operating environment occurs. Automation is only partially context aware. For example, a CAT III autoland system cannot cope with a runway incursion. Human intervention is required (see Bainbridge, 1987 for more 'ironies of automation').

In terms of economy and reliability the autothrottle and autopilot can fly the aircraft more smoothly, accurately and economically than a pilot. They adapt to environmental disturbances faster and can fly complex thrust management schedules. As a result, aircraft can be operated more economically under autoflight control and can function more smoothly, producing less 'wear and tear' thereby reducing maintenance costs. Furthermore, the onboard sensors and automation allow for more precise control and navigation allowing shorter flying times, and hence increasing efficiency. In some sections of airspace vertical separations are being reduced to 1,000 feet and in Free Flight area aircraft are required to self assure in-trail separations.

However, despite the apparent operational efficiency gains described it has yet to be completely established if automation reduces whole lifecycle costs. Modern aircraft are equipped with multiple automation modes to endow them with as much flexibility as possible. This has benefits and drawbacks. Flexibility increases the range of responses available to a pilot in a given situation, but can also overburden them during critical periods of high workload. More options increase the cognitive demands on the pilot. They must now be familiar with all the modes available and knowledge of how and when to apply them. For example, the Airbus A320 has nine autothrottle modes, ten vertical navigation modes and seven lateral navigation modes. This places considerable training demands on pilots, hence simultaneously increases costs and opportunity for error.

Dekker (2004) further attempts to disabuse the notion that automation reduced labour costs. He points out that automation made some crew redundant (e.g. the radio operators, navigators and flight engineers) but the pilots left to fill the gaps remaining were required to attain competencies beyond their original job mandates. As a result, automation *increased* the need to invest in human expertise. Dekker and Hollnagel (1999) suggest that procurement of new equipment is often driven by a trade-off between labour-intensive low-tech systems (with lesser training requirements) and high-tech systems for which it will be expensive to train and retain operators. Taking an even broader view, the design, development, certification, production and maintenance of highly automated aircraft is undoubtedly far more expensive than that for a simpler machine. Once training costs are also incorporated, the question still remains; taking into account the whole lifecycle of the aircraft, do these costs associated with highly automated aircraft outweigh the operational efficiency gains?

Notwithstanding the previous argument, there are two factors with their roots in the societal Medium which severely limit any further efficiency gains in the human element of the socio-technical system of operating a commercial aircraft. Firstly, the operating regulations require a minimum of two qualified flight deck crew (Code of Federal Regulations, Title 14; Joint Airworthiness Requirement – Operations [JAR-OPS]). Until the regulations are changed, no matter how highly automated the aircraft is, the airline will still be required to place two highly qualified, highly paid pilots on the flight deck. Secondly, many departure and arrival air traffic control procedures still cannot exploit the automation available in modern aircraft. This is as a result of such factors as the arrangement of the airspace near the airport, air traffic procedures not congruent with the automaton and/or a lack of knowledge on the part of Air Traffic Controllers about utilising the capabilities of a modern Flight Management System to best effect. As a result, the flight crew have to semi-manually 'fly' the aircraft and most automation is not particularly 'efficient' in these circumstances. Flight deck automation has reduced crew workload where it was already low (*e.g.* in the cruise) but has increased it dramatically where it was already high, *e.g.* in terminal manoeuvring areas. Wiener (1989) called this 'clumsy' automation. Basically, the human pilot will always be needed as automation is never fully context aware.

CONCLUSIONS

Significant increases resulting from enhancements in the efficiency of the (hu)*Man* component of the system alone are unlikely. The Mark I Human Being cannot easily be re-designed. As a result the whole system has to be designed around the capabilities and limitations of the end user, be it pilot, air traffic controller or ground staff. When the human being is pushed towards its operating limits in an effort to increase efficiency, decreases in overall efficiency may result, as argued in the attempts to increase efficiency on the airport ramp. However, when the capabilities and limitations of the human are better understood, then efficiency and safety benefits may accrue, as described in the section on flight crew rostering. In one instance it was forgotten that *Management* involves people. In the other aspect, perhaps because it was blatantly obvious, it was central to the plan.

Operational efficiency will only be marginally enhanced through changes made solely to the *Machine* or *Medium* component. Automation does not replace human work; it merely changes its nature. Two members of flight crew (as a result of the regulatory *Medium*) will still be required on the flight deck. Significant changes in efficiency could be achieved by operating aircraft with a single member of flight crew (up to 18% of direct operating costs in commuter aircraft are crew related). There is the potential to fly safely with a single pilot. The military operate complex aircraft with one pilot on a regular basis. Intelligent automation to aid and monitor the pilot has been under development for sometime (e.g. Schulte and Stütz, 2001; Stütz and Schulte, 2001). Furthermore, removing one crew member may actually enhance certain aspects of safety. Poor crew communication has been implicated in many accidents (Civil Aviation Authority, 1998). Removing one pilot removes this error mode! However, as has been argued, high levels of automation may not actually reduce costs. Savings on flight crew may be offset by other factors in design, operation and maintenance. Changes in the structure of airspace (and the resulting nature of operations) which may lead to large potential gains in efficiency can only be exploited if the aircraft (*Machine*) is equipped to do so and the crew and trained in a complementary fashion.

Perhaps the greatest lesson, though, is that significant changes in efficiency will not be driven by changes in the (hu)*Man*, *Machine* or *Mission* alone. Revolution is required, not evolution. Ultimately, changes in efficiency are dictated by what the *Medium*, in the form of society and legislation, will tolerate and these aspects of the *Medium* are risk averse. Neither Human Factors nor Engineering can be considered in isolation from its sociotechnical context.

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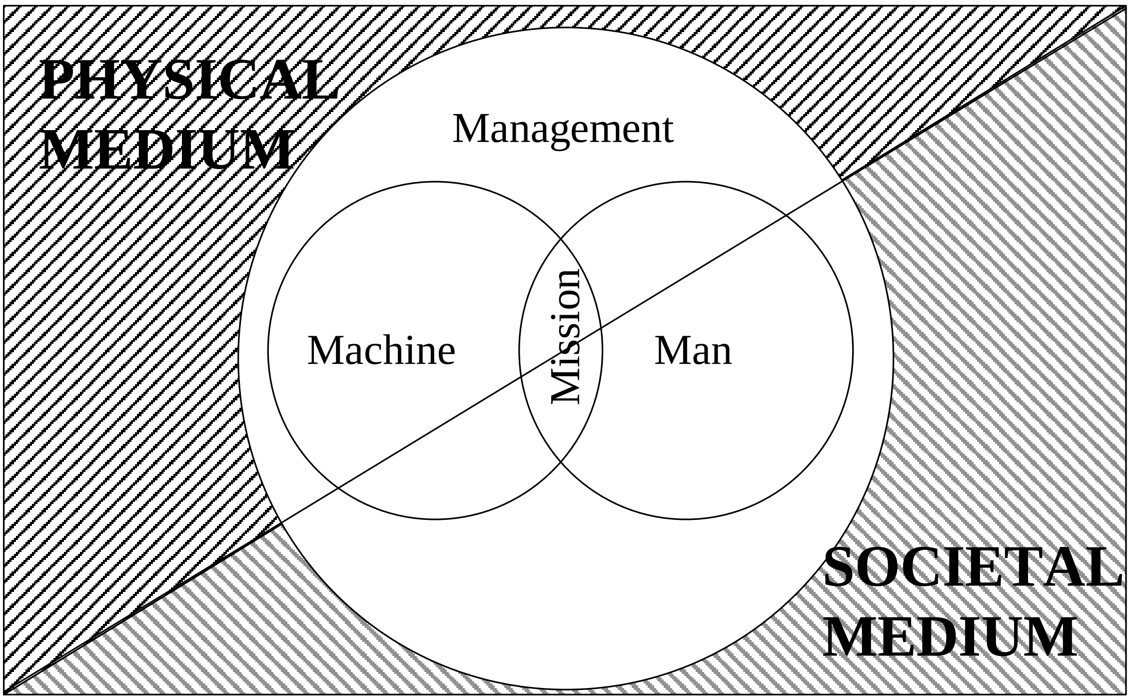

Figure 1 The Five 'M's Model

BIOGRAPHY

Don Harris is Reader in the Department of Human Factors, Cranfield University. His research interests are in flight deck design, system safety and defence human factors. He is Co-Editor in Chief of the journal *Human Factors and Aerospace Safety* and sat on the FAA/JAA Working Group to devise flight deck certification requirements.